

Multi-timescale Solar Cycles and the Possible Implications

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Abstract

Based on analysis of the annual averaged relative sunspot number (ASN) during 1700 – 2009, 3 kinds of solar cycles are confirmed: the well-known 11-yr cycle (Schwabe cycle), 103-yr secular cycle (numbered as G1, G2, G3, and G4, respectively since 1700); and 51.5-yr Cycle. From similarities, an extrapolation of forthcoming solar cycles is made, and found that the solar cycle 24 will be a relative long and weak Schwabe cycle, which may reach to its apex around 2012-2014 in the vale between G3 and G4. Additionally, most Schwabe cycles are asymmetric with rapidly rising-phases and slowly decay-phases. The comparisons between ASN and the annual flare numbers with different GOES classes (C-class, M-class, X-class, and super-flare, here super-flare is defined as $\geq X10.0$) and the annal averaged radio flux at frequency of 2.84 GHz indicate that solar flares have a tendency: the more powerful of the flare, the later it takes place after the onset of the Schwabe cycle, and most powerful flares take place in the decay phase of Schwabe cycle. Some discussions on the origin of solar cycles are presented.

Keywords Solar cycle — Sun: extrapolation — Sun: flares

1 Introduction

It is well known that the Sun is an unique star which affect the geo-space environment extremely. Any variations of solar activities may greatly affect many sides

of human living, from satellite operations, radio-based communication, navigation systems, electrical power grid, and oil tubes, etc. Therefore, it is very important to understand when and how the solar activity will take place in the near future. There are many people who had made such endeavors (Hiremath, 2008; Hathaway, 2009; Strong, Julia, & Saba, 2009; etc). However, we have much of uncertainties (Pesnell, 2008) to present the details of the forthcoming solar cycles. The film **2012** reflects public misgivings to the imminent impact of solar fierce eruptions around the year of 2012.

There are many methods to predict the solar cycle 24 and the beyond. The Solar Cycle 24 Prediction Panel in October 2006 made a comprehensive list of prediction methods including precursor, spectral, climatology, recent climatology, neural network, physics-based, etc (Pesnell, 2008). However, the investigation of periodicity of solar activity is a groundwork for solar cycle prediction. In previous works, many kinds of periodic modes are found from the analysis of different solar proxies (e.g., yearly averaged sunspot number, cosmogenic isotopes, historic records, radiocarbon records in tree-rings, etc.), for example, the 11-yr solar cycle, 53-yr period (Le & Wang, 2003), 78-yr period (Wolf, 1862), 80 - 90-yr period (Gleissberg, 1971), the 65-130 yr quasi-periodic secular cycle (Nagovitsyn, 1997), 100-yr periodic cycle (Frick et al, 1997), 101-yr period cycle (Le & Wang, 2003), 160 – 270-yr double century cycle (Schove, 1979), 203-yr Suess cycle (Suess, 1980). Otaola & Zenteno (1983) proposed that long term cycles within the range of 80 – 100 and 170 – 180 yr are existed certainly.

Sunspot number is the most commonly predicted index of solar activity. The number of solar flares, coronal mass ejections, and the amount of energy released are well correlated with the sunspot number. The present work mainly applied the annual averaged relative sunspot number (ASN) during 1700 – 2009 to study

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the long-term variations, and found some meaningful insights of the forthcoming solar solar activities. This paper is arranged as following: section 2 presents the investigation of periodicity of solar activity and their main features. Section 3 gives some implications of solar cycles, such as the extrapolation of the forthcoming Schwabe cycle 24, the distribution of the solar flares, and the possible origin of solar cycles. Section 4 is the conclusions and some discussions.

2 The Periodicity of Solar Activity and its Main Features

It has been realized for a long time that the solar activity is connected tightly with the solar magnetic field. The energy released in solar eruptive processes is coming from the magnetic field. Hence the variations of solar magnetic field will be a physically reasonable indicator for the solar activity. The sunspot number presents a perceptible feature of the solar magnetic field, which can be regarded as a commonly predicted solar activity index. So, in this work, we adopt ASN during 1700 – 2009 to investigate the periodicity of the solar long period activities. The data set is downloaded from the internet: <http://sidc.oma.be/sunspot-data/>.

The upper panel in Fig.1 presents the profile of ASN during 1700 – 2009, and the lower panel is a Fourier power spectra of the fast Fourier transformation (FFT) from ASN. Here presents 3 obvious spectral peaks which indicate that the strongest periodicity is occurred at 11 years (P_0), the second strongest periodicity is at 103 years (P_1), and the mildly periodicity is at a period of 51.5 years (P_2).

2.1 11-yr cycle (P_0)

The most remarkable feature in Fig.1 is the solar cycles with about 11-yr periods, it is the well-known Schwabe cycle. As ASN reaches to the minimum 2.9 in 2008, and then increases slightly to 3.1 in the year of 2009. After coming into 2010, it becomes stronger obviously than the past two years, there occurred several GOES M-class flares in the first two months. So we may confirm that the end of solar cycle 23 and the start of solar cycle 24 is occurred around 2008. There are 28 Schwabe cycles during 1700 – 2009. They are numbered by an international regulation since 1755. The solar cycle 1 started from the year of 1755, the solar cycle 23 ended around 2008. During 1700 – 1755, there are 5 solar Schwabe cycles. We may numbered them as *A*, *B*, *C*, *D*, and *E* respectively, which presented in the upper panel of Fig.1.

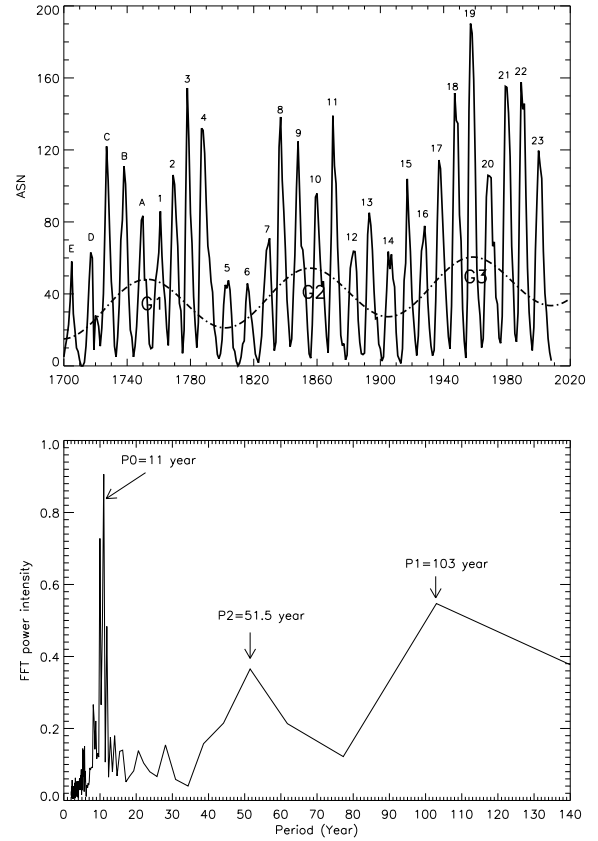


Fig. 1 The upper panel is temporal profile of ASN during 1700 – 2009 (solid curve). The thick dot-dashed curve is a fitted function which shows the secular cycle with period of about 103 years. The lower panel is the corresponding Fourier power spectra of the Fast Fourier Transformation.

In order to investigate the profile of each solar Schwabe cycle more detail to get more useful insights, we may define several parameters:

(a) rise-time (t_u), defined as from the starting minimum to the maximum of a solar cycle in unit of year;

(b) decay-time (t_d), defined as from the maximum to the next minimum of a solar cycle in unit of year;

(c) the profile of solar Schwabe cycles is always asymmetric, i.e., taking less time to rise to the maximum than reaching to the next minimum. We may define an asymmetric parameter as ($Asy = t_u/t_d$). When $Asy = 1$, the profile is symmetric; $Asy < 1$ is left asymmetric, $Asy > 1$ is right asymmetric;

(d) maximum ASN (N_{max}), which may represents the ASN amplitude of each Schwabe cycle.

Table 1 lists all parameters of Schwabe cycles since 1700. The last two lines in the Table present the mean value and the standard deviation of above parameters.

Table 1 indicates that the rise-time of Schwabe cycles is in range of 3 – 7 years (the longest rise-time is 7 years in cycle 7), with the averaged length of 4.4 years, and the standard deviation of 1.2 years; the decay-time of Schwabe cycles is in range of 3 – 11 years (the longest decay-time is 11 years in cycle 4), with the averaged length of 6.6 years, and the standard deviation of 1.2 years; the period of Schwabe cycles is in range of 9 – 14 years, with the averaged length of 11 years, and the standard deviation of 1.3 years.

2.2 103-yr secular cycle (P_1)

The distribution of ASN amplitudes of Schwabe cycles shows clearly the existence of 103-yr cycle, we call such long-term cycle as secular cycle. Gleissberg firstly implied the existence of secular solar cycle, so we also call it as Gleissberg cycle (Gleissberg, 1939). In fact, the secular cycle is consistent with the appearance rate of the Grand Minima, such as the Spörer Minimum around 1500, the Maunder Minimum around 1700 (1645 – 1715, Eddy, 1983), the Dalton Minimum around 1800 (1790 – 1820). From the distribution of ASN amplitudes of Schwabe cycles we may also find that around 1900 (Schwabe cycle 14) seems also a Grand Minimum. In other word, each of the Grand Minima is possibly occurred in a vale between two secular cycles.

In order to show clearly the secular cycles, we make a fitted empirical function with sinusoidal shape by using a method similar to the square-least-method: at first we assume the sinusoidal function in following formation:

$$R_{0i} = A + B \cdot \sin\left(\frac{2\pi}{C}y_i + D\pi\right) + Ey_i \quad (1)$$

Table 1 List of characteristic parameters of solar Schwabe cycles during 1700 – 2009. t_{start} , t_u , t_d , P , Asy , R_{max} is the start time, rise-time, decay-time, period, asymmetric parameter, and the maximum ASN, respectively. Av and dev are the averaged value and the standard deviation of the related parameters, respectively. The star * marks the bottom of the each secular cycle.

| Cycle | t_{start} | t_u | t_d | P | Asy | N_{max} |
|-------|-------------|-------|-------|------|--------|-----------|
| E^* | 1700 | 5 | 6 | 11 | 0.83 | 58 |
| D | 1711 | 6 | 6 | 12 | 1.00 | 63 |
| C | 1723 | 4 | 6 | 10 | 0.67 | 122 |
| B | 1733 | 5 | 6 | 11 | 0.83 | 111 |
| A | 1744 | 6 | 5 | 11 | 1.20 | 83.4 |
| 1 | 1755 | 6 | 5 | 11 | 1.20 | 85.9 |
| 2 | 1766 | 3 | 6 | 9 | 0.50 | 106.1 |
| 3 | 1775 | 3 | 6 | 9 | 0.50 | 154.4 |
| 4 | 1784 | 3 | 11 | 14 | 0.27 | 132.0 |
| 5* | 1798 | 6 | 6 | 12 | 1.00 | 47.5 |
| 6 | 1810 | 6 | 7 | 13 | 0.86 | 45.8 |
| 7 | 1823 | 7 | 3 | 10 | 2.33 | 70.9 |
| 8 | 1833 | 4 | 6 | 10 | 0.67 | 138.3 |
| 9 | 1843 | 5 | 8 | 13 | 0.63 | 124.7 |
| 10 | 1856 | 4 | 7 | 11 | 0.57 | 95.8 |
| 11 | 1867 | 3 | 8 | 11 | 0.38 | 139.0 |
| 12 | 1878 | 5 | 6 | 11 | 0.83 | 63.7 |
| 13 | 1889 | 4 | 8 | 12 | 0.50 | 85.1 |
| 14* | 1901 | 4 | 8 | 12 | 0.50 | 63.5 |
| 15 | 1913 | 4 | 6 | 10 | 0.67 | 103.9 |
| 16 | 1923 | 5 | 5 | 10 | 1.00 | 77.8 |
| 17 | 1933 | 4 | 7 | 11 | 0.57 | 114.4 |
| 18 | 1944 | 3 | 7 | 10 | 0.43 | 151.6 |
| 19 | 1954 | 3 | 7 | 10 | 0.43 | 190.2 |
| 20 | 1964 | 4 | 8 | 12 | 0.50 | 105.9 |
| 21 | 1976 | 3 | 7 | 10 | 0.43 | 155.3 |
| 22 | 1986 | 3 | 7 | 10 | 0.43 | 157.6 |
| 23 | 1996 | 4 | 8 | 12 | 0.50 | 119.6 |
| 24* | 2008 | (5) | (7) | (12) | (0.71) | (56.3) |
| Av | — | 4.4 | 6.6 | 11 | 0.72 | 105.9 |
| dev | — | 1.2 | 1.4 | 1.3 | 0.40 | 37.8 |

Here, y_i represents the time from 1700 (with unit of year). Then let the following sum to become minimum:

$$Q(A, B, C, D, E) = \sum [R_i - R_{0i}]^2 \rightarrow Min. \quad (2)$$

In above equations, R_{0i} and R_i present the values of the fitted empirical function and the observations of ASN, respectively. As Equation (1) is a nonlinear function, we couldn't obtain the true values of parameters A, B, C, D, and E from the standard square-least-method. However, we may try to list a series of [A, B, C, D, E] and calculate the values of $Q(A, B, C, D, E)$, respectively. Then find out the minimum value of $Q(A, B, C, D, E)$ and the corresponding parameters of [A, B, C, D, E]. The thick dot-dashed curve in the upper panel of Fig.1 is the fitted empirical function, which can be expressed as:

$$R_0 \approx 15[2.00 + \sin(\frac{2\pi}{103}y + \frac{3}{2}\pi)] + 0.06y. \quad (3)$$

From the empirical function we may find that the period of long-term variation of ASN is 103 years, which is very close to the secular cycle. We may numbered the secular cycles as *G1* (includes the Schwabe cycle E – A, and 1 – 5), *G2* (includes the Schwabe cycle 6 – 14), *G3* (includes the Schwabe cycle 15 – 24), and *G4* (after the Schwabe cycle 24) since 1700, respectively marked in Fig. 1. At present the Sun is in a vale between *G3* and *G4*. The last term in the right hand of Equ.(3) implies that secular cycles have a gradually enhancement, and the Sun may have a tendency to become more and more active at the timescale of several hundred years.

Many previous studies also presented the evidences of the secular cycles (Nagovitsyn, 1997; Frick et al, 1997; Le & Wang, 2003; Bonev, Penev, & Sello, 2004; Hiermath, 2006, etc.). The Grand Minima (e.g., Spörer Minimum, Maunder Minimum, Dalton Minimum, etc) implies that the Sun might have experienced the dearth of activity in its evolutionary history. And there is no complete consensus among the solar community whether such grand minima are chaotic or regular. This work may confirm the periodicity of the solar secular cycles.

2.3 51.5-yr cycle (P_2)

From the upper panel of Fig.1 we can not get the obvious evidence of the cycle with period of 51.5 yr. However, the evidence is very strong in the Fourier power spectra in lower panel of Fig.1. In fact, from the upper panel of Fig. 1 we may find something of that, around each peak of the secular cycle, the Schwabe cycles are

in mildly weak amplitudes in ASN. Secular cycles seem to segment into two sub-peaks. For example, the solar Schwabe cycle A and 1 around the peak of *G1*, the solar Schwabe cycle 10 around the peak of *G2*, and the solar Schwabe cycle 20 around the peak of *G3*. Possibly, these facts are the indicator of the existence of P_2 component.

Le & Wang (2003) investigated the wavelet transformation of ASN series from 1700 – 2002, and found the evidence of solar cycles with period of 11-yr, 53-yr, and 101-yr. In this work, the ASN series is spanned from 1700 – 2009, and we rectify the periods as 11-yr, 51.5-year, and 103-yr. Our results are very close to that of Le & Wang (2003). Additionally, we find that there is an interesting phenomenon: $P_1/P_0 = 9.36$ is obviously departed from any integers; however, $P_1/P_2 = 2.00$ is fitly equal to an integer of 2. This evidence shows that P_1 and P_2 are originally connected with each other, and P_2 seems to be a second harmonics of P_1 . However, there is no such relationships between P_0 and P_1 , P_2 .

Table 1 presents another interesting feature: most of the asymmetric parameters are less than 1.00 (there are 22 Schwabe cycles with $Asy < 1.00$ among the total 28 cycles, and the proportion is 78.5%), the averaged value of asymmetric parameters is about 0.722, and this implies that most Schwabe cycles are left asymmetric. They have rapidly rising phases and slowly decay phases. And the cycle evolution cannot be modelled by some simple amplitude-modulated sinusoids. Such phenomenon is called as Waldmeier effect (1961). Among the total 28 cycles, there are only 3 Schwabe cycles with symmetric profiles, and 3 Schwabe cycles with right asymmetric profiles. The symmetric cycles (No.D, No.5, and No.16) are very close to the vale of the secular cycles. The No.7 cycle is a bizarrerie for the super long rise-time (7 years) and super short decay-time (3 years) with a super large asymmetric parameter ($Asy = 2.33$). Additionally, there is an anti-correlated relationship between asymmetric parameter and maximum ASN among 28 solar Schwabe cycles. The correlate coefficient is -0.55. i.e. the stronger the solar Schwabe cycle, the more left asymmetric the cycle profile.

3 The Possible Implications of the Solar Cycles

3.1 Extrapolation of the Forthcoming Solar Cycles

It is very important to forecast the forthcoming solar cycles. Many people make great efforts on this problem (Pesnell, 2008; Hiremath, 2008; Wang et al, 2009;

Strong & Saba, 2009; Hathaway, 2009; etc). According to the main Features of long-term solar activity periodicity, we may also make an extrapolation of the forthcoming solar cycles. Firstly, we note that solar Schwabe cycle E, 5, and 14 are located in the bottom of secular cycles, and have rise-time of 4–6 years. At the same time, the solar Schwabe cycle 24 is also possibly seated in a bottom between $G3$ and $G4$. Then, it is reasonable to suppose that the rise-time of the solar Schwabe cycle 24 will be in the range of 4 – 6 years, i.e., its maximum will occur around 2012 – 2014. The another important fact is that all durations of the three bottom solar Schwabe cycle (cycle E, cycle 5, and cycle 14) are 12 years, which are relatively long duration Schwabe cycles. Based on the similarity, we may deduce that the length of Schwabe cycle 24 will also last for about 12 years, which is longer a bit than the normal periods of solar Schwabe cycles.

According to variations of the magnitude of solar cycles (expressed as ASN), we can make some extrapolations for the forthcoming solar cycles. From Table 1, we know that the averaged magnitude of ASN among the 28 solar Schwabe cycles during 1700 – 2009 is 105.9 with a standard deviation of 37.8, and the three bottom cycles (cycle E, 5, and 14) have the ASN magnitude from 47.5 to 63.5. From the above investigations we know that solar Schwabe cycle 24 may also be a bottom cycle, then we have no other reason to suppose that solar Schwabe cycle 24 will have an ASN magnitude of exceeding the range of 47.5 – 63.5, it is a really relative weak solar Schwabe cycle. However, this value is lower than the most results listed in the work of Pesnell (2008), but it is consistent with the result of Badalyan, et al (2001).

Fig. 2 plotted the extrapolation of the forthcoming solar Schwabe cycles by the similarity of the trend-line

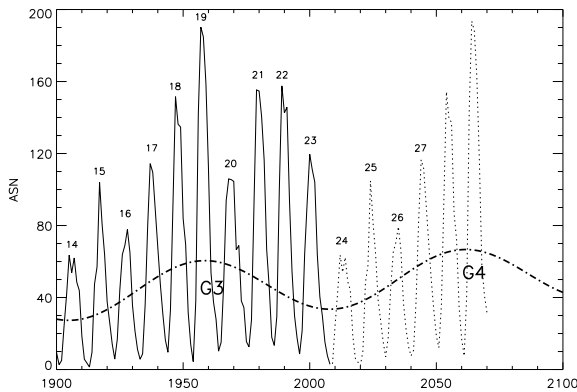


Fig. 2 The extrapolations of the forthcoming secular cycle 4 ($G4$), the solar Schwabe cycle 24 and the beyond.

induced from Fig.1. It shows that the position of solar Schwabe cycle 24 is very close to the valley between the secular cycle $G3$ and $G4$, which is very similar to the solar Schwabe cycle 5 in the valley between $G1$ and $G2$, and the solar Schwabe cycle 14 in the valley between $G2$ and $G3$. So it is very reasonable to extrapolate that the solar Schwabe cycle 24 will be similar to that of the solar Schwabe cycle 5 and cycle 14. This similarity implies that the Schwabe cycle 24 will be a relatively weak activities.

Based on these similarities and Equ.(1), we may plot the extrapolated ASN of the subsequent solar Schwabe cycles and the secular cycle $G4$ in Fig.2. From these extrapolations, we may find that solar Schwabe cycle 24 will reach to the apex in the year of about 2012 – 2014, and this cycle may last for about 12 years or so. It will be a long, but relatively weak Schwabe cycle.

3.2 Distributions of Solar Flare Events in a Schwabe Cycle

When and what kind of solar flare events will occur is also an intriguing problem. Fig.3 presents comparisons between ASN and the distributions of the appearance rate of solar flares and the annual averaged solar radio flux (arbitrary unit) at frequency of 2.84 GHz around the solar Schwabe cycle 23. The appearance rate of C-class, M-class, and X-class (limit from X1.0 to X9.9) flares are presented by their annual flare numbers, and the appearance rate of the super-flares (here we define the super-flare as $\geq X10.0$) are presented by their related GOES soft X-ray class. The vertical dashed line marks the time of magnetic maximum of solar Schwabe cycle 23. The 2.84 GHz solar radio flux is observed at Chinese Solar Broadband Radiospectrometer (SBRs/Huairou) (Fu et al, 2004). The data set of the annual flare numbers is compiled from GOES satellite at soft X-rays (<http://www.lmsal.com/SXT/homepage.html>).

From Fig.3 we may find an obvious tendency: the more powerful solar flares are inclined to occur in the period after the maximum of solar Schwabe cycle (presented by the two tilted-dotted lines). For example, the ASN of solar Schwabe cycle 23 reaches to its maximum in about 2000, and the annual number of C-class flares and M-class flares reach to the maximum in about 2001, while the annual number of X-class flare reaches to its apex in about 2002, the most concentration of the super-flares is occurred in 2003. During the whole Schwabe cycle 23 (1996 – 2008) there are 12995 C-class flares, 1444 M-class flare, 119 X-class flares, and 6 super-flares. Among them there are 7414 C-class flares (57.1%), 950 M-class flare (65.8%), 80

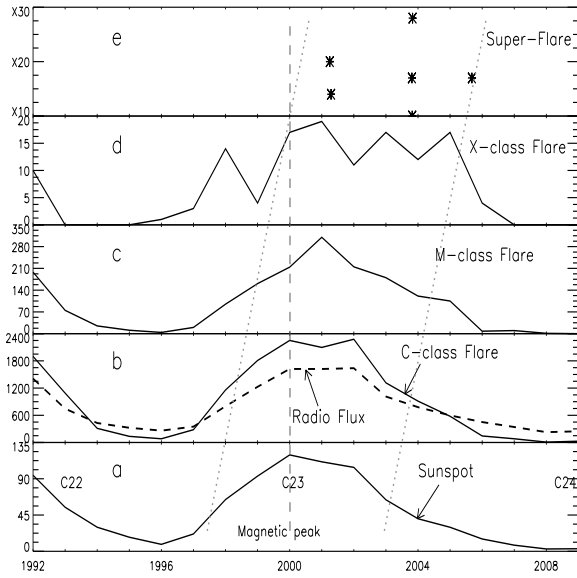


Fig. 3 Comparisons between ASN (a) and the distribution of the strength of solar flares and the annual averaged solar radio flux (the dashed curve in panel (b), in arbitrary unit) at frequency of 2.84 GHz around the solar Schwabe cycle 23. The appearance rate of C-class (b), M-class (c), and X-class flares (d) are presented by the annual flare numbers, and the appearance rate of the super-flares are presented by the related GOES soft X-ray class (e). The vertical dashed line marks the time of magnetic maximum of cycle 23. The two tilted-dotted lines show the trend of the flare distribution.

X-class flares (67.2%) and all the super-flares are occurred after the year of ASN apex (2000) of the cycle. In 2005, which is very close to the magnetic minimum of cycle 23, there are 18 X-class flares occurred. Additionally, the annual averaged solar radio flux (in panel b) at frequency of 2.84 GHz are very similar to the profile of the annual C-class flare numbers. Generally, the solar radio emission at 2.84 GHz is mainly associated with the non-thermal eruptive processes. It shows that all of the 6 super-flares ($> X10$) occurred in the decay phase of the Schwabe cycle 23, including the the largest flare event (X28, 2003-11-03) recorded in NOAA so far. These facts imply that the stronger flare events are inclined to occur in the decay phase of the Schwabe cycle. However, so far we can not make a doubtless conclusion because we have no enough reliable observation data of the other Schwabe cycles.

The above characteristics of the solar flare distribution in solar Schwabe cycles is also implied the asymmetric properties of the Schwabe cycles. However, it is most intricate that most of the powerful flares are occurred not in the rising-phase but in the decay-phase.

3.3 Discussions on Solar Cycle Mechanism

In this work, we make an assumption that future behaviors of the solar activity in upcoming several decades years can be deduced from the averaged behaviors in the past several hundred years. And this can be accepted because the several hundred-year is so much short related to the life-time of the Sun when it is at the main sequence. We may regard the Sun as a steady-going system which will run according to its averaged behaviors of its past several hundred years and last for several hundred years again.

The time-scales of the solar 11-yr Schwabe cycle and 103-yr secular cycles are much shorter than the diffusion time-scale of solar large-scale global magnetic field structures (about 3×10^7 yr, Stix, 2003), and much larger than the solar dynamical time-scale (for example, the 5-min oscillations, etc). The origin of these cycles is a remarkable unsolved tantalizing problem. We need to explore some theoretical models which may carry the energy from the interior to the surface and release in solar atmosphere in some periodic forms. Presently, there are two kinds of theoretical models for solar cycles, one is turbulent dynamo models, the other is MHD oscillatory models. However, both of them have much difficulties to interpret the main features of solar cycles reliably (Hiremath, 2009).

As for the 11-yr Schwabe cycle, in spite of much of difficulties, possibly dynamo theory is the most popular hypothesis to explain the generations (Babcock, 1961;

Leighton, 1964, 1969). This model finds its origin in the tachocline where strong shearing motions occur in the solar internal plasma, store and deform the magnetic field, and can give a semi-empirical model of solar 11-yr cycle and reproduced the well known sunspot butterfly diagrams. At the same time, there are several other approaches. Polygiannakis & Moussas (1996) assume that the sunspot-cycle-modulated irradiance component may be caused by a convective plasma current, this current can drive a nonlinear RLC oscillator. This model can describe the shape and the related morphological properties of the solar cycles, and give some reasonable interpretations to the long period inactive Maunder Minimum.

The closeness between the 11-yr Schwabe cycle and the 11.86-yr period of Jupiter has been noted for a long time. And this let us to speculate that planetary synodic period may resonate with solar activity (Wood, 1975). Grandpierre (1996) proposed that the planetary tides of co-alignments can drive the dynamo mechanism in the solar interior and trigger solar eruptions. They calculate the co-alignments (conjunction and opposition) of the Earth, Venus, and Jupiter and find that their co-alignment periods are in the range of 8.7588 – 13.625 yr, the averaged value is around 11.2 yr, being very close to the observed Schwabe cycle of 11-yr. However, de Jager & Versteegh (2005) compare the accelerations due to planetary tidal force, the Sun's motion around the gravitational center of the solar system, and the observed acceleration at the level of tachocline, and find that the latter are by a factor of about 1000 larger than the former two, and assert that the planetary tidal force can not trigger the dynamo mechanism observably. However, in my opinion, as the plasma system is always very brittle, even with a very small perturbation, a variety of instabilities are also very easy to develop, accumulate, and trigger a variation as the solar Schwabe cycle. Hence, at present stage, it is very difficult to confirm which factor is the real driver of solar Schwabe cycles.

The most bewildering is the harmonic relationship between the long-term cycles P_1 and P_2 . This may imply that solar long-term active cycles have wave's behaviors. However, so far, we don't know more natures of this kind of cycles. The dynamo theory can give some reasonable interpretation to the 11-yr solar Schwabe cycle, but it can not present even if a plausible explanation to the 51.5-yr cycle and 103-yr secular cycle so far. In 1943, Alfven assumed that solar large-scale dipole magnetic field has the axis coincide with the rotation axis, and the magnetic disturbance in the interior travels along the field line to the surface at Alfven speed. This magnetic disturbance will excite

MHD oscillation and transport to the whole Sun, the travel time of the MHD oscillation is about 70 – 80 yr. This time scale is neither agree with the 11-yr period, nor with the time scale of the secular cycles.

Many people believe that the 11-yr solar Schwabe cycle is originated from the tachocline which is a thin shear layer of strong differential rotation motion at the base of the solar convection zone (Dikpati, 2006). Helioseismology suggests that the tachocline is thin of the order of 1% of the solar radius (Christensen-Dalsgaard & Thompson, 2007). It is well-known that the Kelvin-Helmholtz instability is very easy to develop around a layer with strong shear motion. From the work of Gilliland (1985), we know that the time scale of Kelvin-Helmholtz instability for the whole Sun is 3×10^7 yr. Then it is possible to assume that the time scale of Kelvin-Helmholtz instability around the thin tachocline can be reduced to the order of 100-yr. Rashid, Jones, & Tobias (2008) pointed out that the evolution of the hydrodynamic instability of the slow tachocline region will occur on timescale of hundred years. However, we need much of investigations to confirm this assumption and to understand the long-term solar cycles. The origin of long-term solar cycles is still a big unsolved problem.

4 Conclusions

From the above analysis and estimations, we obtain the following conclusions:

(1) besides the well-known 11-yr solar Schwabe cycle, two long-term solar cycles, 103-yr secular cycle (Gleissberg cycle) and the 51.5-yr semi-secular cycle are identified;

(2) the solar Schwabe cycle 24 is in a vale between the two secular cycles (G3, and G4), it will be a relatively weak and long active cycle, which may reach to its apex in about 2012-2014 and last for about 12 years;

(3) most solar Schwabe cycles are left asymmetric, they have rapidly rising phases and slowly decay phases. The most intriguing is that most of the solar powerful flares occurred in the decay-phase of the solar Schwabe cycle.

(4) the secular cycle is possibly associated with the solar inner large scale motions as well as the dynamo processes can be account for the 11-yr Schwabe cycles. However, there are much of works need to do to understand the mechanism of the secular cycles.

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